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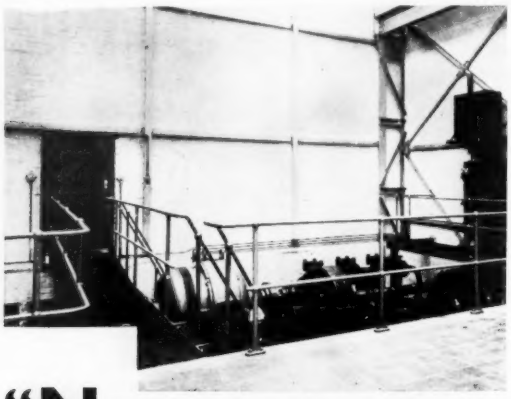

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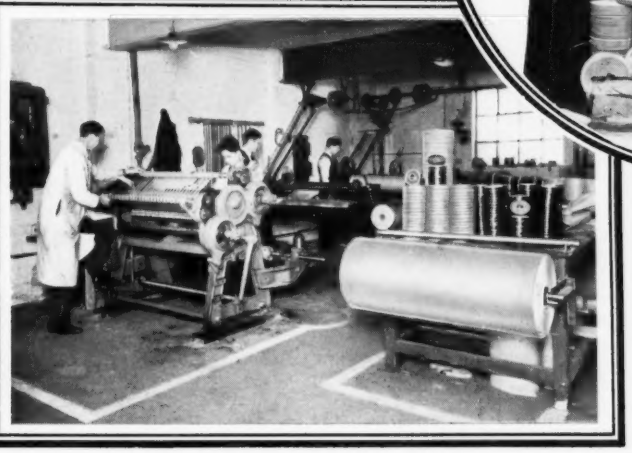

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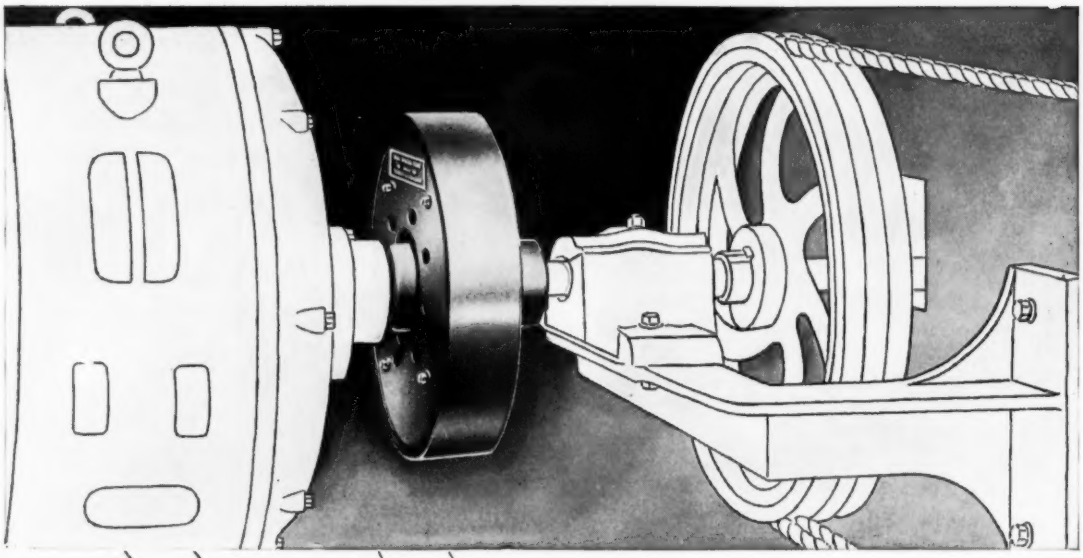

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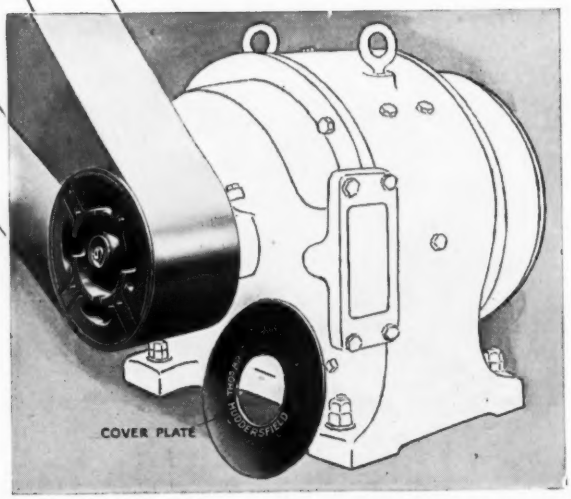

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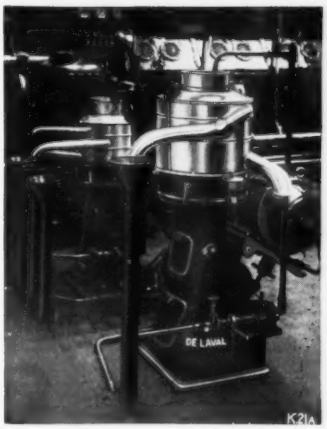

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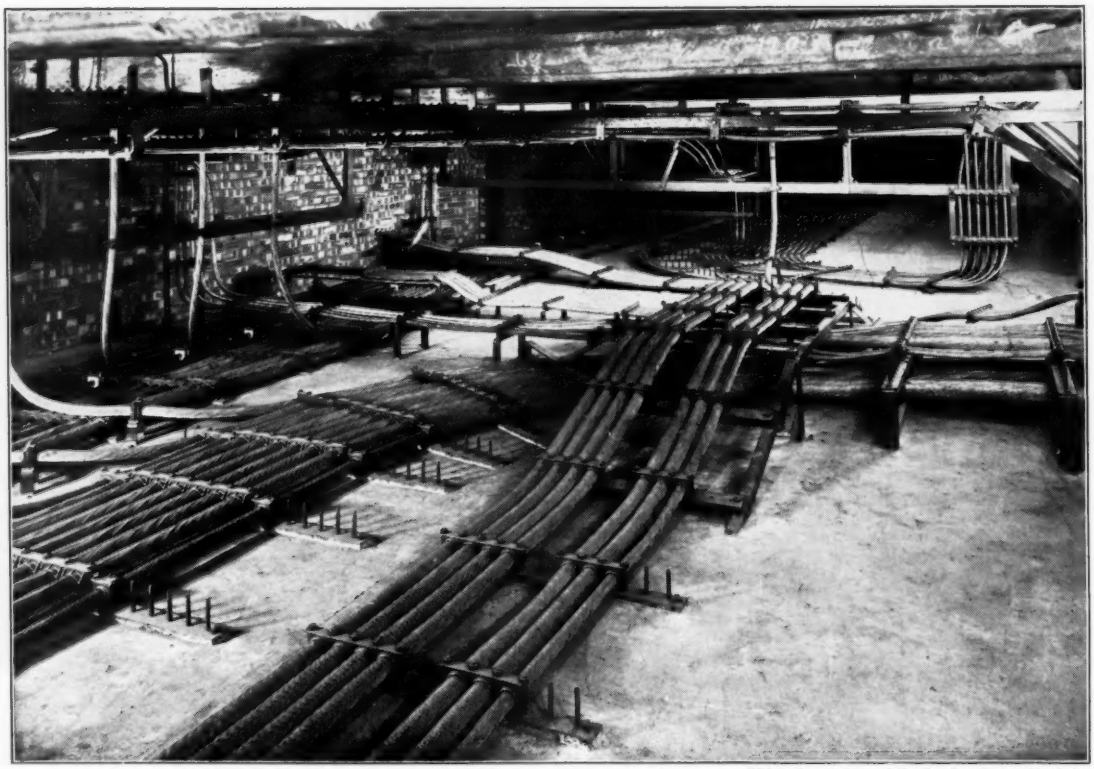

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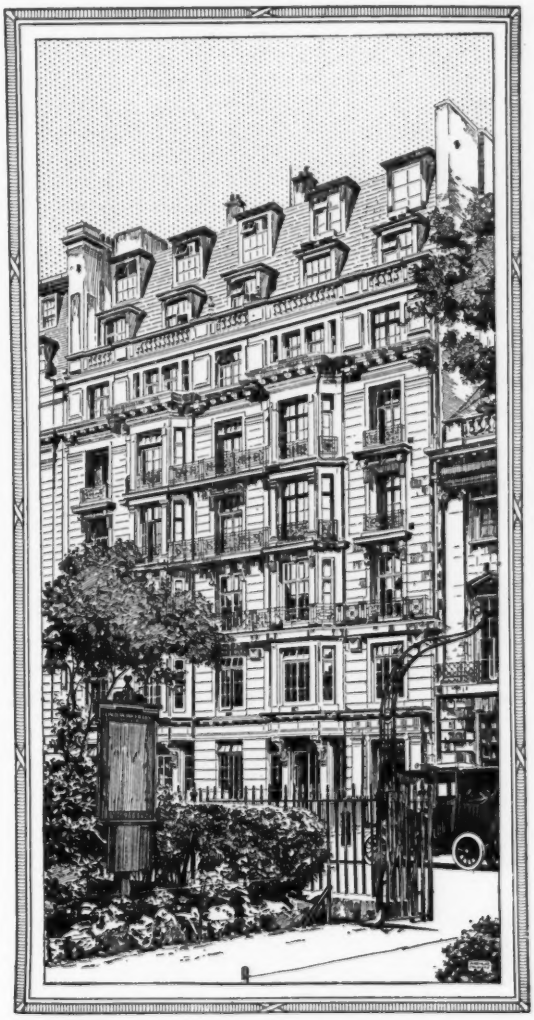

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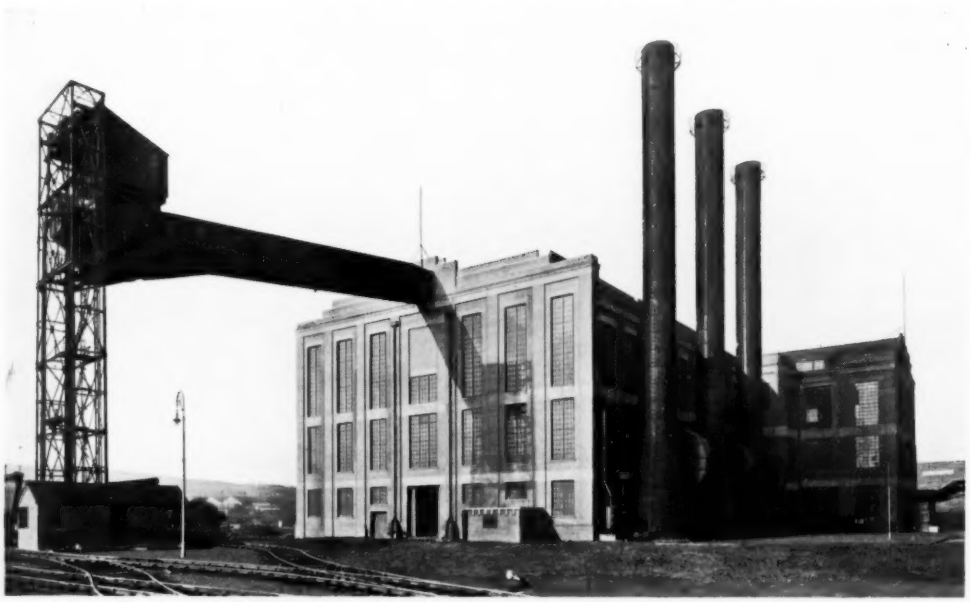
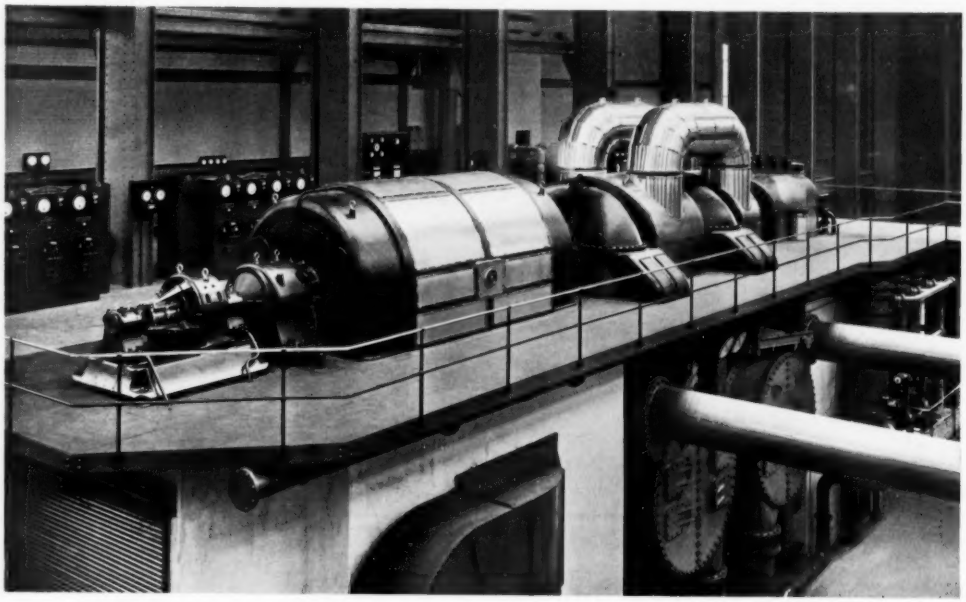
Blackburn Meadows Power Station, Sheffield.



The New Power Station Buildings and Coal Gantry.



The 25,000 kW., 11,400 Volt, 3,000 R.P.M., "English Electric" Turbo-Alternator Unit.

The English Electric Journal

Vol. VI. No. 5 MAY, 1933 One Shilling.

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All Communications respecting Editorial Contents should be addressed to The Editor, The English Electric Journal, The English Electric Company Limited, Stafford.

EDITORIAL.

On April 6th H.R.H. Prince George, in the presence of a distinguished company, inaugurated the supply from the new Power Station of the Sheffield Corporation at Blackburn Meadows. This Station represents the latest and best practice in central station design, and of particular interest are the excellent layout of the buildings, with their large window space, the very complete plant for the handling of fuel and ash, the use of purified sewage effluent for the large volume of cooling water required for the condensers, and the large multi-cylinder steam turbine plant installed by this Company. Sheffield has the fifth largest municipal electricity undertaking in this country, and the high overall efficiency of the undertaking is indicated by the fact that the price per unit for power is the lowest of the five.

The plant manufactured and installed by the English Electric Company is described in this issue, and it is to be noted that in all the Company has supplied 11 steam turbine units for the Sheffield undertaking, these units having a total capacity of 120,000 kilowatts.

Reference has previously been made in the pages of this Journal to the contract placed with the Company by the Danish State Railways for traction equipments for the electrification of the Copenhagen Suburban Lines. A large number of these equipments have now been delivered by the Company, and a description of the motors and control gear is given herein.

As the majority of our readers are aware, the name "Dick-Kerr" has been associated with traction and road transport work since the latter part of the last century, and to-day the English Electric Company, in the same Works at Preston, is manufacturing many types of vehicle for both electrical and internal combustion engine propulsion. Among the most recent types put into service is a long-distance motor coach, which has become known as the Dick-Kerr "Luxury Coach." This coach has proved so successful in service that orders for 18 similar vehicles have been received from a large transport company in Lancashire, in addition to further individual orders for other districts.

A useful contribution to the study of Rural Electrification was made in the early part of this year in an address given in Belfast by a member of the Company's staff. In the course of the address he dealt with many of the problems confronting supply engineers, and suggested ways in which the manufacturer of electrical equipment could assist in their solution. The paper is published herein as it was presented, and will be concluded in our next issue.

In the article on "Industrial Motors," continued from our last issue, readers will doubtless find particular interest in the "built-in" type of motor, which the Company has developed for inclusion as an integral part of the machine it has to drive. This type of motor, specially designed for the purpose, represents an important step in the individual driving of many classes of industrial machines.

"Sheffield Electricity."

Some notes on the new Power Station at Blackburn Meadows, Sheffield, with a description of the "English Electric" Turbo-alternator Unit.

The City of Sheffield had its first public supply of electricity so far back as 1878. When the Corporation purchased the undertaking in 1898 there were 694 consumers, the annual output was 978,000 units, and the plant had a total capacity of 1,725 kW.

The Neepsend Power Station, opened in 1904, included two turbo-alternator sets of 1,500 kW. each; a third unit of 4,000 kW. being added in 1910. By 1914 about one-third of the ultimate capacity of the station had been developed, and by 1917, so great were the demands caused by the manufacture of munitions, the station reached its full development.

By March, 1918, the capacity of the plant had increased from 17,500 kW., in 1914, to 68,225 kW., and the maximum demand had risen from 14,934 kW. to 57,338 kW.

The Blackburn Meadows site was purchased in 1917, and after some delay owing to post-war conditions, the new station was opened by H.R.H. the Duke of York in October, 1921.

The total capacity of the plant installed was 28,000 kW., but, as the demand for electricity continued to increase, it was found necessary to replace several of the sets at Neepsend by larger machines, and also to install a 10,000 kW. interconnecting line with Rotherham.

From March, 1913, to March, 1933, the number of units sold increased from 21 millions to 222 millions, a very striking achievement despite the depression from which the steel industry has suffered during recent years.

The new Blackburn Meadows Power Station has been designed and completed to the specifications of Mr. Ernest Morgan, M.I.E.E., A.M.Inst.C.E., A.M.I.Mech.E., the General Manager of the Electric Supply Department. It is illustrated in our frontispiece, and forms the first section of a generating plant which will have an ultimate capacity of 100,000 kW. The buildings are designed to accommodate two 25,000 kW. generating units with their boilers and auxiliaries, the first of which has now been installed.

The generating plant for this section of the station comprises a turbo-alternator with a continuous output of 25,000 kW of 11,400-volt 3-phase alternating current, running at 3,000 r.p.m.; surface condensers, feed heating apparatus, feed pumps, and the necessary instruments for the observation and control of the economical working of the plant. The principal contractors for the generating plant have been the English Electric Company, Limited, who have previously manufactured for the Corporation large generating units of similar design but smaller output.

Ernest Morgan, M.I.E.E., A.M.Inst.C.E., A.M.I.Mech.E., General Manager of The Electric Supply Department.

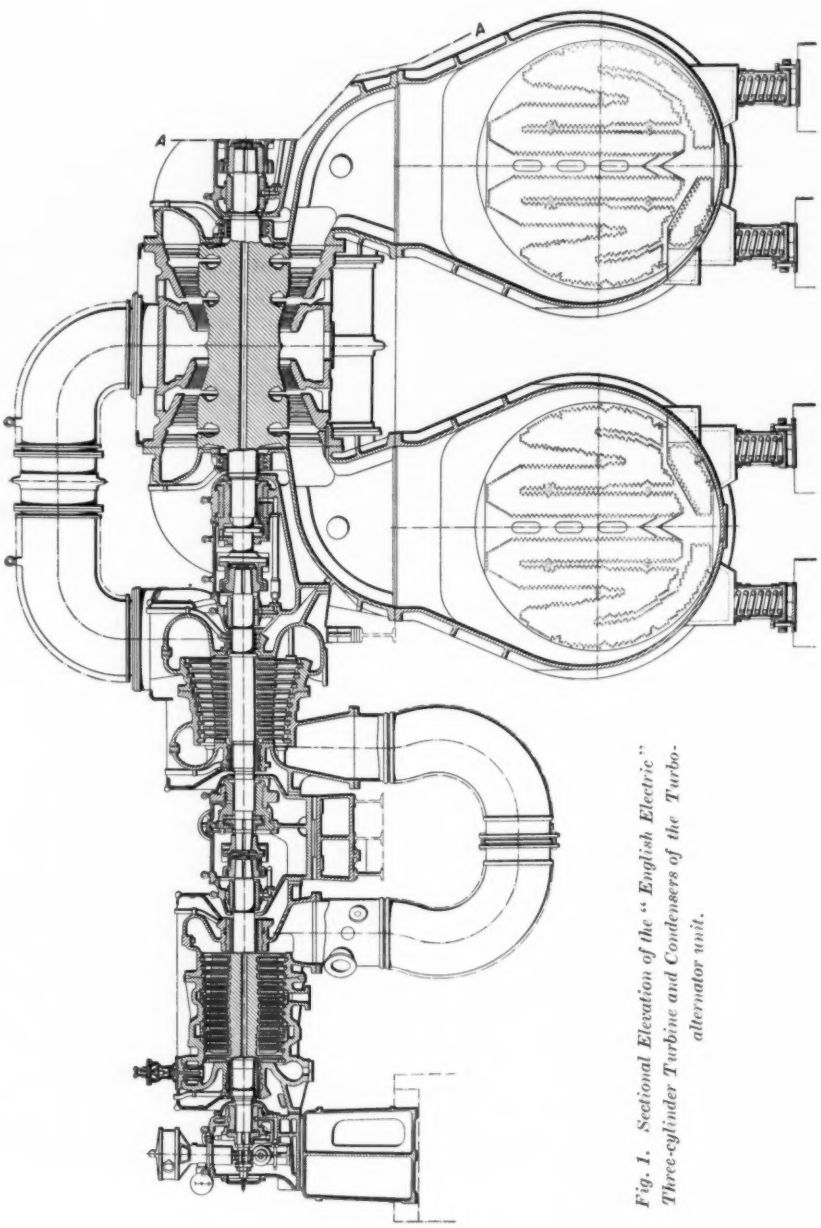


Fig. 1. Sectional Elevation of the "English Electric" Three-cylinder Turbine and Condensers of the Turbo-alternator unit.

Fig. 2. The steam end of the 25,000 kVA, 11,400 Volt, 3,000 R.P.M., Turbo-Alternator.

The turbine may be described as a three-cylinder tandem unit consisting of a high-pressure casing and an intermediate casing, both having impulse blading, and a double-flow low-pressure casing with reaction blading. This type of steam turbine, operating at the high speed of 3,000 r.p.m., represents the most modern design for such an output, and gives important advantages which may be summarised as a combination of high steam economy with sound design and low stresses.

Steam enters the turbine stop valve at a gauge pressure of 570 lbs. per square inch and a total temperature of 770° F., and exhausts into twin surface condensers capable of maintaining a vacuum of 28.37 ins. of mercury with the barometer at 30 ins. and cooling water at 80° F. when the set is carrying a load of 20,000 kW. The steam enters the high-pressure casing by way of a separator, a main stop valve and throttle valve, passes from this casing to the intermediate casing through a pipe underneath the turbine floor, and then flows to the low-pressure casing through two pipes carried overhead. The low-pressure portion consists of a casing arranged on the double-flow principle, so that steam enters at the centre and flows in opposite directions towards the exhaust ends and twin condensers. The complete assembly is mounted upon the foundations in such a way as to allow the necessary freedom for expansion without in any way disturbing the alignment of the various parts. A sectional elevation of the turbine and condensers is shown in Fig. 1.

The high-pressure rotor carries fourteen impulse stages, the intermediate rotor nine impulse stages, and each flow of the low-pressure rotors ten reaction stages. Although the design of the rotors is such that they are to some extent axially balanced, provision is nevertheless made to receive any end thrust by the incorporation of Michell thrusts at suitable points. Smooth running of the set is further ensured by the fitting of couplings of the flexible type between adjacent rotors as well as between the turbine and the alternator. On plant of this description a thoroughly reliable oil service is of the utmost importance ; this is provided by a main oil pump of the gear type, driven from the steam end of the

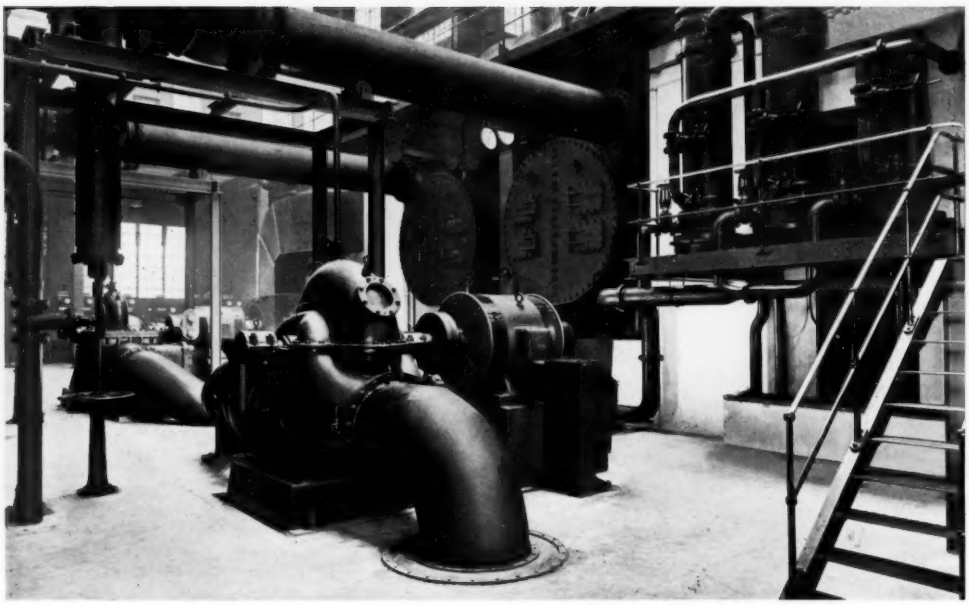


Fig. 3. The Two Circulating Water Pumps, each having a capacity of 909,000 gallons per hour, against a total head of 50 ft. The motors are 410 H.P. running at 725 R.P.M.

high-pressure rotor through worm gearing and an auxiliary pump of the centrifugal vertical-spindle type driven by a small steam turbine. The latter is brought into action automatically by an oil relay when the oil pressure falls below a certain value.

The throttle valve is actuated in the usual way from oil relays controlled from the governor and pilot valve. The main throttle valve governs the turbine directly up to approximately 18,000 kW. The higher loads are obtained by a full load nozzle valve and two overload valves which are brought into operation by further movement of the throttle valve acting through oil-operated relays.

An emergency governor of the out-of-balance ring type is mounted on the turbine shaft, and when this comes into action due to overspeed, or if the oil pressure fails, the throttle valves and main stop valve are closed automatically.

The exhaust steam from the double-flow low-pressure portion of the turbine is condensed in twin condensers of " English Electric " patented design, in which there are over 10,000 tubes for the flow of the necessary cooling water ; the latter is supplied at the rate of $1\frac{3}{4}$ million gallons per hour from the culvert of the cooling towers, by two Worthington-Simpson centrifugal pumps, which discharge it through the condensers and return it to the towers. The condensed steam is withdrawn from the condenser and discharged to the feed system by either of the two full-duty extraction pumps.

A carefully designed feed system, shown in the diagram Fig. 4, ensures that maximum use is made of feed heating by steam tapped from the turbine, and the feed water is heated up by this means to a final temperature of 350° F. at the economical load of the set. Both the latent heat and the sensible heat of the tapped steam are transferred to the condensate before its return to the boilers, thus reducing the amount of heat to be finally dissipated at the cooling towers. The condensate passes in turn through the air ejector heater, the drip cooler, the evaporator heater, and the low-pressure bled heater, and then enters the booster pump, which discharges it through high-pressure feed heaters to the high-

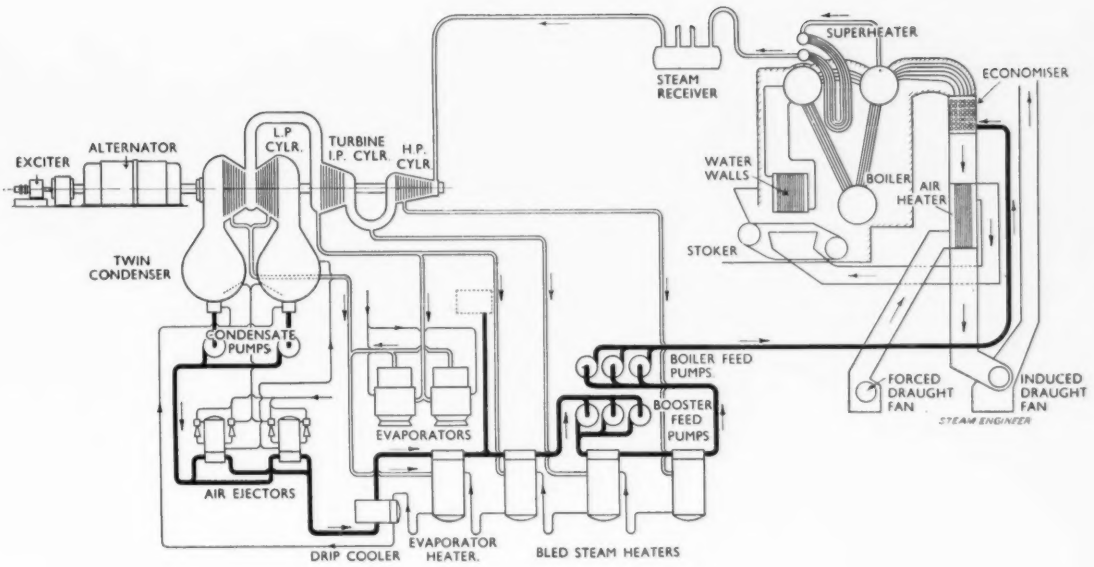


Fig. 4. Feed Heater Diagram.

pressure feed pump that feeds the boilers. A surge tank is provided to allow for any difference between the quantity of water coming from the condenser and that required for the boilers; it also controls automatically the admission of make-up water to the system and has the interesting feature that it is sealed from the atmosphere. Make-up water is provided by two evaporators, each having a capacity of 10,000 lbs. per hour.

Of the three sets of booster and feed pumps two sets are electrically driven and one steam driven; each is capable of discharging 25,000 gallons per hour against a pressure of 730 lbs. per square inch.

In view of the high economy of which such an equipment is capable, every facility has been provided for observing and controlling the operation and performance of the turbine and its auxiliaries. The complete set of instruments that is fitted in convenient situations for easy supervision of the plant includes steam flow meter, Venturi condensate test indicator, 19-point distance thermometer, temperature and pressure indicators, vacuum meter, oxygen recorder, water tester, tank level indicators and alarms.

The steam turbine drives an alternating-current generator capable of giving a maximum continuous output of 25,000 kW. in the form of 3-phase current at a frequency of 50 cycles per second and a pressure of 11,000/11,400 volts, the power factor being 0.8; a sectional elevation of the alternator is shown in Fig. 5. This machine is conservatively rated, and tests on similar alternators of "English Electric" manufacture indicate that the actual temperature rises under service conditions will be lower than those guaranteed. As in the case of the turbine plant, full provision has been made for observing the behaviour of the unit, and for this purpose twenty-four thermo-electric temperature detectors are embedded in the stator core and windings and connected to a temperature indicator through a selector switch.

The alternator is ventilated on the closed-circuit principle; air is forced through the machine by an external motor-driven fan at the rate of about 75,000 cubic feet per minute, and

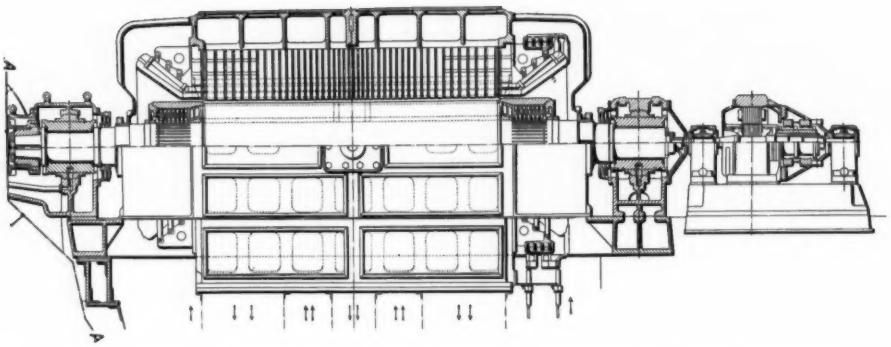


Fig. 5. Sectional Elevation of the "English Electric" Alternator of the Turbo-alternator unit.

the heat is extracted in a cooler through which water is circulated. The cooling air enters at the ends as well as at the intermediate belts along the outside periphery of the stator core, and tests have shown that this system results in a very high degree of uniformity in the temperature along the entire length of the machine.

The stator frame is a strongly ribbed iron casting provided with internal dovetails into which fit corresponding projections on the laminations of the stator core. The laminations, which are of special alloy steel of high permeability and low losses, are separated from the frame by suitable insulation, and during manufacture each lamination is carefully treated to remove any burrs formed during the punching process, and adequate insulation is applied to the surface. In assembling them, radial ducts are formed at short intervals to allow the cold air to enter and heated air to escape.

The stator winding is of the Company's standard design, carried in open slots in the core and arranged with end connections of the basket type. The slot portion is secured by treated wedges of tough material and the end portions rest on substantial non-magnetic support rings. The form of the coils has been carefully designed with a view to obtaining the best possible wave form and minimum loss, and to reduce the eddy currents each conductor is divided into a number of strips arranged in parallel with suitable transposition carried out in two steps.

In a machine of this size operating at a speed of 3,000 r.p.m. special care has to be given to every detail of the design and construction of the rotating part or rotor. The body of this is formed from a solid carbon steel forging, and suitable axial slots are machined to receive the winding and for ventilation purposes. The winding is secured in the slots by means of steel and bronze keys, and the end portions are held together in the strongest possible way by retaining rings of special alloy steel. Metallic packings are placed between the end portions to improve the solidity of the mass and to assist in heat conduction. Current is supplied to the rotor through two steel sliprings, one at each end, and is furnished by means of an exciter of the two-bearing type driven from the outer end of the alternator shaft through a flexible coupling. Regulation of the voltage of the alternator is carried out entirely by controlling the comparatively small current in the shunt field of the exciter.

The whole of the 22 motors driving the various pumps, stokers, fans and auxiliaries were also supplied by the English Electric Company, and range from $3\frac{1}{4}$ H.P. to 410 H.P. and total approximately 3,310 H.P.

In conclusion, it is interesting to place on record that this is the eleventh turbine equipment supplied by the Company to the Sheffield Electricity Department. It brings the total capacity of "English Electric" plant supplied to Sheffield to over 120,000 kW.

Danish State Railways Electrification.

The Danish State Railways have undertaken the electrification of their Copenhagen suburban lines by the 1,500 volts D.C. system with overhead line. The first stage of the electrified line from Copenhagen to Klampenborg, with a branch line to Holte, is shown on the map reproduced in Fig. 1. The line has a total distance of 26 kilometres, about 16 miles, and is to be opened towards the end of this year. The electrified system will be considerably extended later.

The order for the complete electric traction equipment for 42 motor coaches and 21 trailer coaches was placed in July, 1932, with the English Electric Company, Limited, in collaboration with our agents, Messrs. Sophus Berendsen, Ltd., of Copenhagen. The rolling stock is being made in Denmark at the works of Aktieselskabet Frichs and Vonfertrukken Scandia.

On the 15th December, 1932, the first instalment of 5 trailer coach equipments was shipped to Denmark, and this has been followed by successive shipments, the concluding set of 6 trailer coach equipments being shipped on the 17th March, 1933.

A comprehensive inspection and test of the first two motor coach equipments operating under power was carried out at the Bradford Works of the Company from February 27th to 1st March by the Chief Electrical Engineer of the Danish State Railways, and at the successful conclusion of these tests the first two motor coach equipments were shipped on the 10th March.

The trains, when in service, will comprise two motor coaches with one trailer coach between them. Two of these units will form a standard 6-coach train.

The control equipment is of the " All Electric Camshaft " type, which is operating successfully on suburban systems in Madras, Bombay, Capetown, Vancouver, Japan, and in many other parts of the world. The bulk of the control gear is contained in two cases carried on the motor coach underframe. Fig. 2 shows the main control gear with covers in position, and Figs. 3 and 4 show the main and auxiliary control gear with the covers removed. The cases are specially

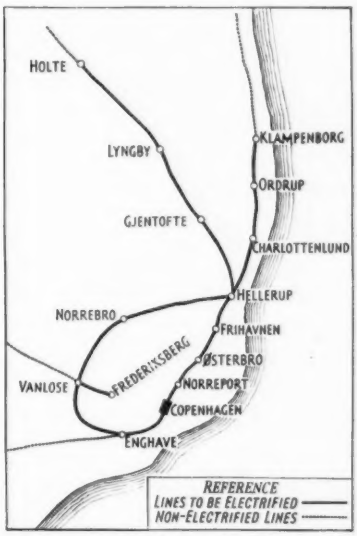


Fig. 1. Sketch map of Copenhagen suburban railway system.

made with dustproof joints to ensure that all dust and snow is excluded. In Denmark, dry snow, of a fine powdery nature, is often experienced ; as this has particularly penetrating properties great care has been exercised in the designs to make full provision against this.

The covers of both gears are interlocked with the 1,500-volt main isolating switch and also with the pantograph air supply, so that the pantographs must be lowered and the main isolating switches opened before the covers can be removed ; thus making all high tension apparatus in the cases quite " dead " and safe to work on.

Two air-operated pantographs are fitted on each motor coach for collecting current from the overhead line. These pantographs have a system of balanced springs which give close regulation of pressure on the overhead line over the full range of operation. Fig. 5 shows a typical pressure regulation curve of a pantograph on test.

The main H.T. circuits are protected by an " English Electric " enclosed type cartridge fuse, which is capable of clearing short circuits on 1,500 volts. In addition to this, when power is

All-Electric Camshaft-Type Control Equipment.

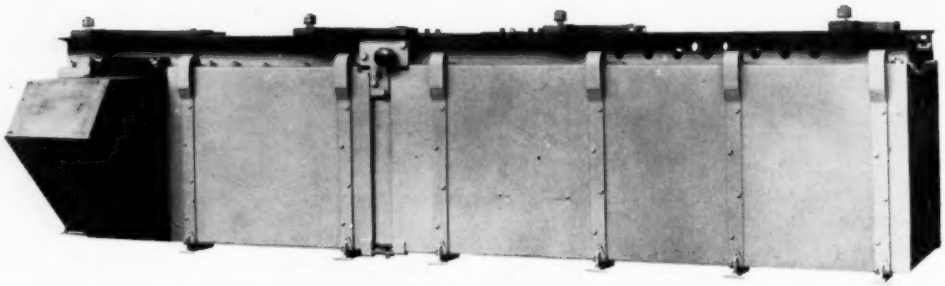


Fig. 2. Front View of Main Control Gear with Covers in position.

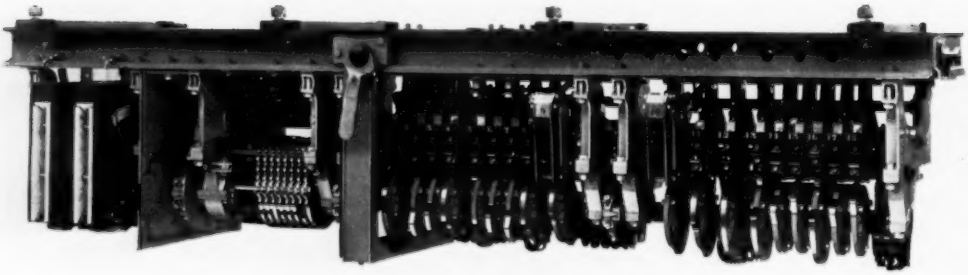


Fig. 3. Main Control Gear with Covers removed.

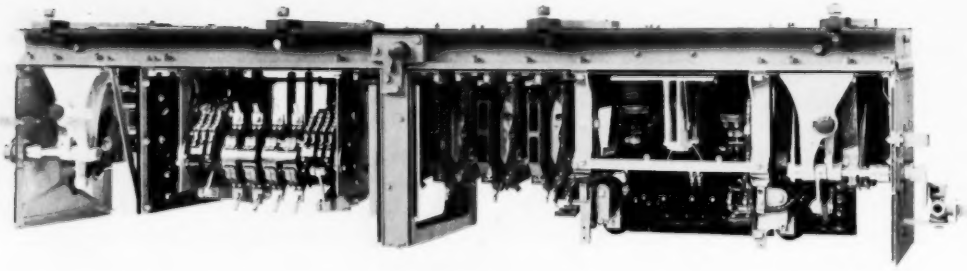


Fig. 4. Auxiliary Control Gear with Covers removed.

shut off during driving, the main circuits are normally opened by a pair of quick-opening cam-operated line circuit breakers. A pair of overload relays, one in each main motor circuit, trip these line-breakers in case of overload.

The design of the cam-operated line-breakers is of unusual interest and is illustrated in Fig. 6. The construction and operation are as follow :—

Two solid cut cams of specially durable material, which are mounted on an insulated square shaft and driven from the main contactor camshaft, close the contacts against powerful springs. These springs give a very quick break on opening, and, in conjunction with the metallic shield blow-out, enable the line-breakers to clear currents due to the heaviest overloads or short circuits.

The operating mechanism consists of two cam rockers, which are pivoted in the middle and carry at one end a roller bearing ; at the other they are connected to the lower extremity of two toggle links. There are two L.T. operating coils, which, when energised, lift clappers which hold the toggle joints straight and enable the main contacts to be closed by the action of the cams. When the operating coil circuit is broken the toggle joints collapse, causing the main contacts to open immediately, irrespective of the position of the camshaft. The clappers also actuate auxiliary L.T. contacts, which set the camshaft motor in the right direction for returning the camshaft to the "off" position immediately the line-breakers are open.

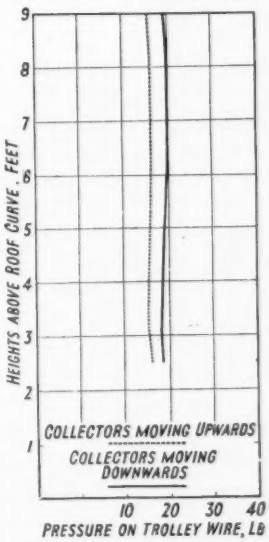


Fig. 5. Pantograph pressure curve.

The control circuits and coach lighting are supplied with current at 65 volts from a 1.8 kW. 1,500/65-volts motor generator set fitted with voltage regulator. The set is mounted on the motor coach underframe, and all generators throughout a train are connected in parallel on to a common L.T. bus-line running through all coaches. The motor generator sets are self-ventilated and draw air through ventilating ducts in the coach body to ensure clean operating conditions for the inside of the sets. In the event of failure of the power supply a 24-volt battery supplies emergency light, and an automatic relay switches in the emergency lights when no 65-volt supply is available.

Fig. 6. Cam-operated Line-breaker.

The main starting resistance is of the "unbreakable" type, two banks of special alloy strip metal being supported in steel frames and mounted on the motor coach underframe. Double insulation of the live elements is provided ; the primary insulation is of mica and the secondary of porcelain, to ensure an ample factor of safety.

Each coach is heated electrically by 12 series-connected units operating on the 1,500-volt circuit. The heating is controlled in stages of one-third, two-thirds and full heat by means of

a remote control switch in the driver's cab operating 1,500-volt contactors in the heater circuit. Each motor coach also supplies heat to half the trailer coach next to it, through semi-permanent heater connection boxes and a jumper cable between the coaches. An interesting feature of the heating system is that a current limit relay cuts the heaters out of circuit during periods of acceleration when the maximum current peaks occur ; consequently, the current peak load on the sub-station is kept down.

When in service, with 1,500 volts on the overhead line, the trains are expected to attain a balancing speed on level tangent track of about 62 miles per hour. The traction motors are of the " English Electric " EE501 type rated at 160 H.P., 750 volts. Two motors are fitted in the bogie at each end of the motor coach, thus making a total of 2,560 H.P. for a 6-coach train of 306 tons. The motors, illustrated in Fig. 7, are self-ventilated, and, like the motor generator, draw their ventilating air through ducts in the coach body to assist in keeping the interior of the motors clean. This system has been used satisfactorily and found highly efficient on the Madras Suburban Electrification of the South India Railway.

The control gear is arranged to give six resistance notches and one field tap notch of 74 per cent., with series grouping of the motors, and five resistance notches followed by two field tap notches of 74 per cent. and 56 per cent. with parallel grouping of the motors. Normal series parallel grouping of the four traction motors

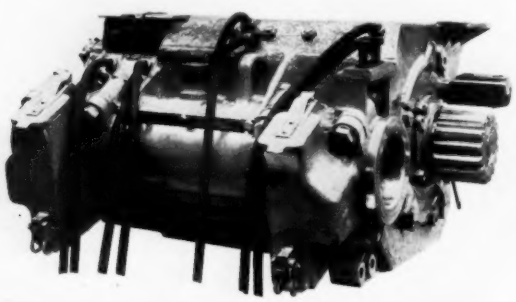


Fig. 7. " English Electric " 160 H.P. Traction Motor.

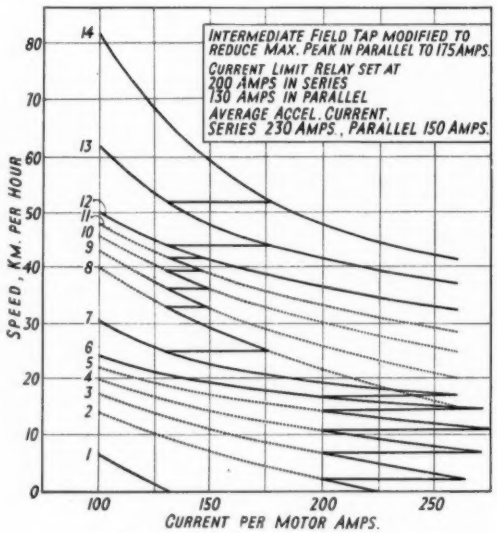


Fig. 8. Main Starting Diagram.

is provided, the motors being arranged in pairs in permanent series. The notching is entirely automatic and controlled by a cam-operated current limit relay fitted on the main control camshaft.

The Danish State Railway specified very careful regulation of the accelerating currents, and this has been made with a view to limiting the peak current demand whilst ensuring good acceleration. In series the notching-up value is 200 amps., and the average value 230 amps. per motor coach ; in parallel this is reduced to 130 and 150 amps. respectively per pair of motors, i.e., 260 and 300 amps. per motor coach. Fig. 8 shows the main starting diagram.

In addition to the above, reduced acceleration for bad rail conditions is also obtained by means of a tapping on the special current limit relay coil. This is controlled by the driver from a push-button switch in the cab.

Four notching positions are given on the master controller :— (1) First series for shunting only. (2) Full series intermediate field tap of 74 per cent. (3) Full parallel. (4) Full parallel field tap 56 per cent.

By this means a very flexible driving control is provided.

The Dick-Kerr Luxury Coach.

This coach, typical of the Company's latest service to Road Transport Organizations and their passengers, has been in use for some time. It is proving very popular on the Blackpool, Birmingham, London route.

The Dick-Kerr Works, Preston, of the English Electric Company has long been associated with the development of Road Transport; from the days of the old cable tramways through all the various developments of Electric Tramcars and Trolley Buses, Petrol Buses, and the long-distance Motor Coaches. It naturally follows that the Company's unrivalled experience and accumulated knowledge of every aspect of road conveyances for large numbers of passengers is reflected in each type of vehicle produced.

This view of the near side of the coach illustrates the pleasing lines.

The Dick-Kerr Luxury Coach represents the very latest development for long-distance motor-coach services. Comfort, rather than ostentatious luxury, has been the predominant aim of the designers, and no feature has been neglected which would contribute to the sense of ease and enjoyment experienced by the passengers. Tasteful decoration, pleasing lines, useful fittings, all contribute their share in conveying to the mind of the passenger a personal enjoyment of the pleasures of motoring, rather than the mere convenience of rapid transport from place to place.

Designed essentially for long-distance service in all weathers, the coach is suitable for mounting on any modern two-axle single-deck chassis having either petrol or compression ignition engines with forward control. The design can, of course, be modified to suit a chassis in which the driver's seat is behind the engine. The body has a sliding roof controlled and operated by the driver. When closed, the roof is quite water-tight and draught-proof. At the rear of the roof is a receptacle for bulky luggage. This is reached by sunk steps of the "cat-ladder" type in the back of the coach. Light hand-luggage, coats and wraps are carried on spacious, substantially built racks, conveniently placed above the side windows of the saloon. Passengers' heavy luggage is stowed in roomy compartments below the floor of the saloon, to which access is obtained from the back and near side of the coach.

This illustration shows the accessibility of the engine, and the ample luggage compartments under the floor of the coach.

Passengers enter and leave the

The interior of the coach, with the sliding roof open.

saloon by a sliding door on the near side at the rear of the vehicle. An emergency exit door is provided at the front of the offside in accordance with the requirements of the Road Traffic Act.

The coach provides ample accommodation for 28 passengers. The seats are of specially comfortable design, well sprung and upholstered, the seats nearest the gangway having arms. At the back of each set is a glove or paper net, an ash tray and a tilting mirror, and under each seat is a comfortable foot-rest. The seats are so arranged, in relation to the windows, that passengers have an unrestricted view of the passing scenes. The windows are provided with the latest type of half-drop fittings throughout. All windows other than the front nearside bulkhead and the windscreen are of $\frac{3}{16}$ in. plate glass.

The saloon is particularly well provided with artificial light. The lamp fittings are of frosted glass in stainless steel frames, and are placed on the underside of the luggage racks. An evenly distributed light, of good intensity, enables every passenger in the saloon to read in comfort.

The minor refinements of the coach furnishings include an eight-day clock, curtains to all windows, and a carpet down the central gangway. The floor is covered with rubber which positively excludes draughts.

All the interior woodwork is of solid walnut, french polished, and the interior panels are covered with moquette which harmonises with the upholstery of the seats.

One of the amenities of the saloon is the heating system. Tubular radiators are fixed at convenient points on the floor; these derive their heat from the radiator of the engine. The bus is well ventilated, yet is free from draughts.

At the back of the coach is a lavatory compartment, which includes a wash basin and supply of running cold water, towel rails and mirrors. A highly hygienic lavatory convenience of the standard chemical type is provided. The windows of this compartment are built up in leaded, obscured glass. If the lavatory compartment is not required the seating accommodation of the coach can be increased to 32.

The driver's compartment has been carefully designed and arranged. The windscreen gives the driver an unobscured, clear view of the road; this, with the ample side windows, gives a good view of traffic signals, approaching and overtaking traffic.

An electric bell in the driver's cab, operated from conveniently placed push buttons in the saloon, provides communication with the driver.

The exterior of the coachwork is panelled with aluminium, finished in the finest quality of materials to any particular colour scheme adopted by the proprietors. Illuminated destination indicators, complete with the latest type of operating gear, are fitted in the roof, over the driver's cab, and illuminated name and number plates in the back of the coach.

The coach is typical of an order for eighteen coaches of this design recently placed with the Company by the Ribble Motor Services, Ltd.

The fine external appearance of the coach, with its fine streamline design, gives a vivid impression of smooth speed and solid comfort. It worthily upholds the traditions of the Dick-Kerr Works, and will enhance the already high reputation of "English Electric" Coach and Bus bodies.

Some Problems of Rural Electrification.

(*Reprint of a Paper read on 18th January, 1933, before the Belfast Association of Engineers, by R. M. CHARLEY, B.Sc., M.I.E.E.*)

Introduction.

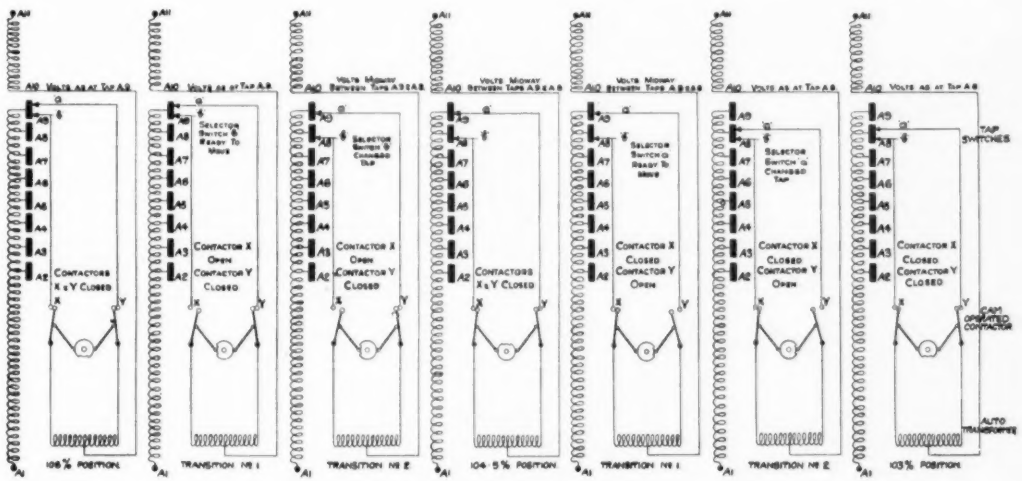
Progress of the "Electrical Age" has been brought home to those who live in rural areas more forcibly by the wonderful benefits they have derived from wireless than by the application of electricity supplied over wires to their domestic requirements. In recent years, however, strenuous efforts have been made by Supply Authorities to make available a plentiful supply of cheap electricity not only for industry, but for use in the humblest dwelling. Large tracts of country in various parts of the world lack many conveniences, such as water supply, or even gas supply, but electric light is installed in every home.

The first essential in making provision for the demand for electricity supply in rural areas is to ensure that generation is done as economically as possible, and, secondly, the supply must have the utmost reliability. The latter feature involves the inter-connection of generating stations and systems, which requires high voltage transmission lines with large transforming stations, and there may be further secondary systems at lower voltages; then at a suitable point the system is tapped to give the local supply at the required voltage.

On-load Tap-changing on Main Transformers.

At each point of connection between stations or systems transformers are required, and they must be arranged so that tappings can be changed while the transformers are on load, not only for voltage regulation but to ensure the best operating conditions in the system. It is interesting to note that on the English "Grid" there is about seven million kVA. of 132 kV. and about two million kVA. of 66 kV. and 33 kV. transformers equipped with on-load tap-changing gear.

Much has been written about the various



TAPPING POSITION	106%	104·5%	103%	101·5%	100%	98·5%	97%	96·5%	94%	92·5%	91%	89·5%	88%	86·5%	85%
TRANSFORMER TAPPING NUMBER	A9	A9	A8	A8	A7	A7	A7	A6	A6	A5	A5	A4	A4	A3	A3	A3	A2	A2
CONTACT 'Q'	○	○		○		○	○		○	○		○	○		○	○		○
CONTACT 'S'	○		○	○	○		○	○	○		○	○		○	○		○	○

○ INDICATES THAT CONTACT IS MADE ON TRANSFORMER TAPPING

Fig. 1. Transformer On-load Tap-changing Gear, Diagram of Connections and Sequence Chart.

methods of on-load tap-changing, but it may be of interest to refer to the scheme illustrated diagrammatically in Fig. 1. On the main winding there are a number of tappings corresponding to half the number of voltages required, and intermediate voltages are obtained by means of an auto-transformer or reactor having a mid-point. The auto-transformer is connected to the tappings by means of a selector switch and a pair of cam-operated contactors, so that it is either connected across a pair of tappings or has both its ends connected to a single tapping. The sequence of operations is shown in Fig. 1. The general principle of this scheme is almost universally adopted, and it may well be applied to small transformers with a simpler arrangement of tap-changing gear.

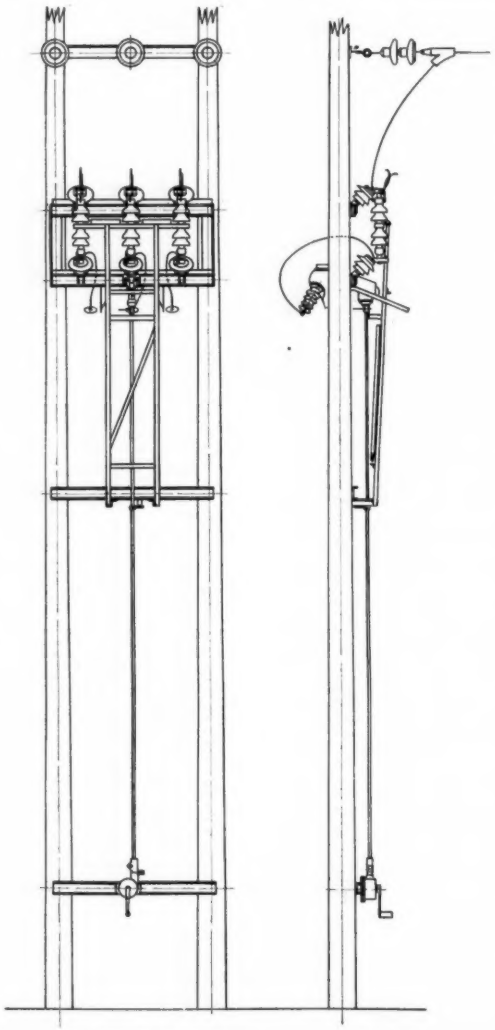


Fig. 2. Typical Arrangement of Switch and Fuse Unit.

Rural Electrification—General.

The above remarks refer to the conception of the main electricity schemes which are now being developed and which will enable the requisite supply in the rural areas to be given. Before this is an accomplished fact, however, many engineering and economic problems have to be solved. I am approaching this subject not with direct experience of the operation of schemes of rural electrification, but as a manufacturer with knowledge of requests from operating engineers for plant best suited to their individual requirements, and in some cases with the satisfaction of having been able to offer assistance in connection with some special problem the engineer has met.

It is a common slogan that rural electrification can only be made to pay if the cost is kept to the lowest possible value. I hold that if this is carried to the extent of installing the cheapest possible equipment a very mistaken policy is being adopted. Admittedly, the scheme must be worked out economically, but there are other factors than initial cost that must be taken into account. I propose to mention briefly the question of switchgear ; then, more in detail, the type of transformer, both as regards mechanical arrangement and electrical performance ; and, finally, I believe it may be of interest to mention voltage regulation equipment, for every operating engineer will, sooner or later, be faced with the problem of overcoming difficulties due to voltage drop.

In the following remarks I propose assuming that the supply available is three-phase, 50 cycles, at 11,000 volts, and that distribution is at 400 volts, three-phase 4-wire. I suggest that the three-phase lines and the neutral wire should be used for the whole of the distribution, except, perhaps, for very small loads where nothing but lighting will ever be required. Single-phase distribution places a serious limit on future extension, particularly where power involving the use of motors is involved. At present three-phase

motors are much more reliable and cheaper than single-phase motors.

Switch and Fuse Gear.

It is probable that the rural scheme will be carried out with an overhead transmission line. The switchgear for the various tapping points must be as simple as possible, and it must give adequate protection to the equipment installed at the tapping point, e.g., the step-down transformer, and also to the main system from which the supply is taken.

The maximum short circuit kVA. of a system depends on several factors, but a fairly safe value that might be adopted as a standard giving a reasonable factor of safety, is 100,000 kVA. The switchgear must be capable of clearing the worst possible fault without causing any disturbance on the main supply system, and it should be capable of grading in order to allow of a certain amount of discrimination in the settings of protective gear installed at different points, and it must maintain such settings permanently.

Various types of switchgear are employed, but that most suited to meet the above requirements is a combination of a plain air-break switch with a cartridge fuse. Such fuses are now available with a guaranteed rupturing capacity of 100,000 kVA. The design is also capable of giving widely different operating times; for example, fuses having the same rupturing capacity can be made to operate under short-circuit conditions in .001 second or as long as .027 second, thus giving the very desirable feature of discrimination. The fuse also has a definite time-current characteristic.

The cartridge fuse is superior to any form of open wire fuse in that its maintenance cost is negligible. The open wire type deteriorates rapidly due to internal heating and atmospheric corrosion, even if an expulsion device is used. It has been the unfortunate experience of some engineers to have to replace the wire in open fuses at unreasonably frequent intervals, without any fuse having functioned in the manner for which it was installed. The solid filling of cartridge fuses

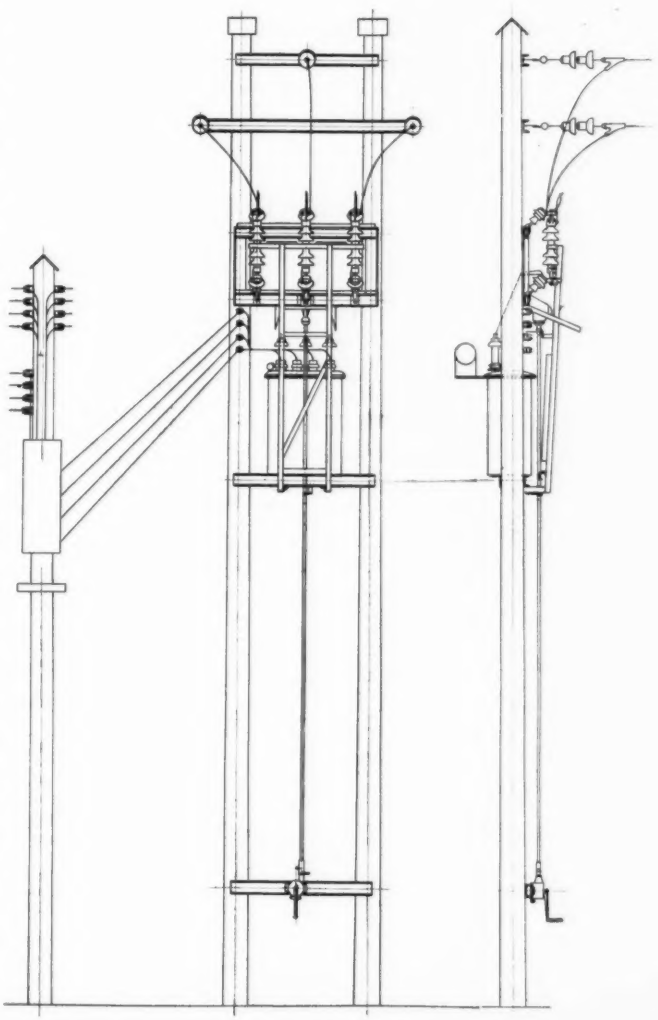


Fig. 3. Typical Arrangement of Switch and Fuse Unit, including Distribution Transformer.

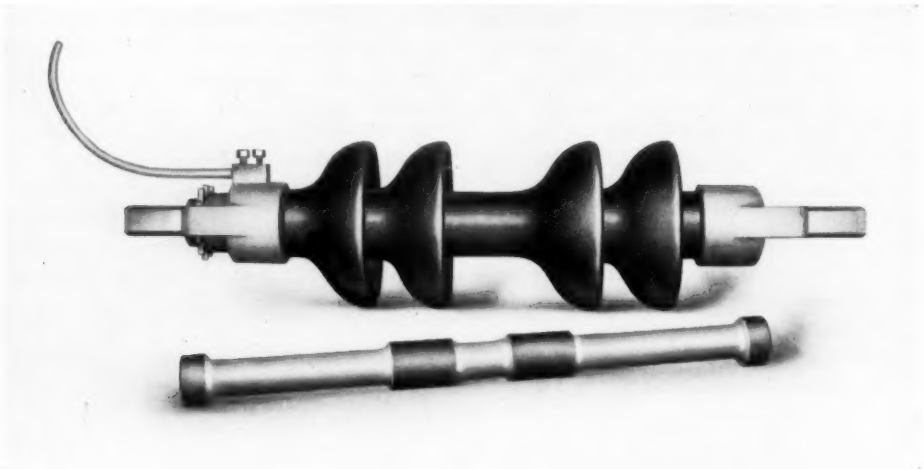


Fig 4. Tubular Insulator and Fuse Cartridge for Switch and Fuse Unit for 11 kV. Service.

has also been found superior to liquid filling of other types owing to evaporation of the liquid.

The most suitable arrangement of the air-break switch is the falling frame type. It enables the operator to replace fuses on the ground, which is a wonderful safeguard as compared with schemes where the operator has to climb the pole, thus running the risk of injury from electric shock or from falling off the pole. The importance of this point is realised more particularly in the night or in bad weather.

Typical arrangements of switch and fuse gear described above are illustrated in Figs. 2 and 3, and a cartridge fuse element suitable for service at 11 kV. and capable of a rupturing capacity of 100,000 kVA. is shown in Fig. 4.

Transformers.

One of the most important items of equipment in a rural scheme of electrification is the step-down transformer. Here, again, I hold the opinion very strongly that the cheapest possible design, from mechanical or electrical considerations, is not the most economical in the long run. Most of such transformers are pole-mounted, and many are installed at remote points difficult of access. Maintenance or repair costs would be very heavy if these were incurred. It is, therefore, of primary importance to build such transformers so that no maintenance will be required and so that the risk of breakdown is extremely remote, even if this means increasing the initial cost by an appreciable amount. In many cases of pole-mounted transformers the cost of replacing one unit would offset the extra initial cost of a more reliable design.

After very careful consideration of this problem from all points of view, I recommend that engineers concerned in rural electrification work will be well advised to install transformers built according to the following ideas, which, I contend, give the greatest measure of reliability and reduce maintenance costs to a minimum.

Transformers—Mechanical Arrangements.

The transformer should be considered as a complete self-contained unit, and the possibility of partial dismantling, other than replacement of bushings, while in position on site, probably up a pole, should not be contemplated. The tank must be completely filled with oil, and an expansion vessel must be provided. This feature maintains the dielectric quality of the oil, and it also ensures that if there is any leakage it will be of oil outwards, whereas with other designs without an oil expansion vessel there may be ingress of the weather to the tank without there being any visible sign until the transformer breaks down. To ensure a thorough and permanent oil-tight joint between the cover and tank, the former should be of very heavy plate bolted to a substantial flange on the tank with the insertion of

an oil-proof packing. The metal surfaces may even be machined. The cover should be slightly domed to give it greater mechanical strength and prevent accumulation of water on it. I believe that the best way to assemble the core and windings in relation to the tank is to support the former from the underside of the tank cover, and to mount both H.V. and L.V. bushings in the cover. It is possible that it may be necessary to replace a bushing while the transformer is in position, and to enable this to be done easily, the bushings should be bolted to the cover and should be provided with detachable caps. It is necessary to withdraw a certain amount of oil when a bushing is to be changed, but a very small quantity is sufficient.

It has always been more or less standard practice for transformers to be provided with tappings, but it is questionable whether these have been used to the best advantage. Obviously, in older designs, where the tappings were brought to a tapping-board under the oil level, there was serious difficulty in changing tappings, especially when the transformer was mounted up a pole or otherwise exposed to the weather. I strongly recommend, therefore, that off-load tapping switches should be provided in practically all cases, and particularly for rural electrification transformers. The extra cost is trifling compared with the great convenience secured, and the resulting more frequent and economical use of the tappings.

Fig. 5 (a). Distribution Transformer.

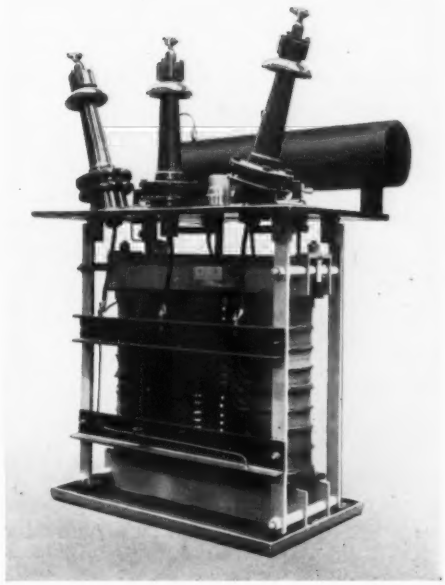


Fig. 5 (b). Core and Windings of Distribution Transformer.

A transformer incorporating the above features is illustrated in Fig. 5. Transformers of this general type may cost 10 per cent., or even 15 per cent., more than the cheapest obtainable, but I am confident that in the long run the extra cost is fully justified, and that operating engineers will be amply repaid for their foresight in installing such transformers.

TRANSFORMERS—ELECTRICAL PERFORMANCE.

In addition to the question of mechanical construction, I believe that it is thoroughly uneconomical to purchase transformers having an efficiency corresponding to the cheapest design. In other words, I maintain that if efficiency is evaluated in an actuarial manner, it will pay the operating engineer to install probably the most efficient transformer the designer can put forward. The iron loss is an

important item, particularly for rural electrification work where the load factor is so low, but I venture to suggest that copper loss is also very important, especially when its relation to voltage regulation is considered.

The question of the evaluation of efficiency has received much more attention on the part of operating engineers recently than hitherto, and I am glad that the Overhead Lines Association has developed a formula which is incorporated in the Specification it has issued in connection with transformers for rural electrification work.

Two methods have been used by various authorities, viz.: By taking as the basis, (1) Total Capitalised Cost, (2) Total Annual Cost. In (1) the cost of the losses are capitalised and the amount is added to the initial cost of the transformer; in (2) the initial cost of the transformer is expressed as an annual charge to cover interest and depreciation and the annual cost of the losses is added. I believe that method (2) is the best for general use in determining which of two or more alternative designs is the most economical. This method has been adopted by the Overhead Lines Association, and I propose to use their formula in presenting several examples.

The formula is—

$$S = r\,£ + 0{\cdot}73d\,(I + FZC) + 0{\cdot}001\,K\,(I + C)$$

where

- S = Cost per year in shillings to cover the operation of the transformer.
- r = Cost per year in shillings per £ to cover interest and depreciation.
- £ = Initial cost of transformer in £.
- d = Cost of electricity in pence per unit at point of installation of transformer.
- I = Iron loss of transformer in watts.
- F = Load Factor expressed as a decimal.
- Z = A factor derived from the difference in area of the load current curve, and a curve of (load current)^2 drawn to a scale such that at full load the two curves coincide.
- C = Copper Loss of transformer in watts at full load.
- K = Cost of electricity in shillings per kVA. or kW. of maximum demand at point of installation of transformer.

Probable values of constants for rural electrification schemes are—

- r = 2 shillings per £ per year.
- d = 0·2 pence per unit.
- F = 15% = 0·15.
- Z = 0·6.
- K = 65 shillings per kVA.

Table A gives the results of the use of this formula applied to 2 designs, A and B, in three sizes of three-phase transformers for service on an 11,000-volt 50-cycle system, the secondary pressure being 400 volts.

TABLE A.

	25 kVA.		75 kVA.		100 kVA.	
	A.	B.	A.	B.	A.	B.
Iron loss ... Watts	243	190	513	400	640	500
Copper loss Watts	700	610	1,600	1,400	2,000	1,500
Regulation at Unity P.F. %	2·83	2·46	2·19	1·9	2·07	1·55
Initial Cost of Transformer £	49–10	53–0	83–0	89–0	96–0	107–0
S = Shillings per year	204	194	399	372	484	437
= £-s. ,, ,,	10–4	9–14	19–19	18–12	24–4	21–17

These examples all show that in spite of the greater initial cost of the more efficient design B, the cost per year is less, and hence it is seen that in the interests of economy the more expensive transformer B should be installed. This comparison is most marked in the largest size, where, as against increased initial cost of 12 per cent., there is a saving of 10 per cent. in the annual cost.

I also want to draw attention to the fact that the higher efficiency design also has much better regulation, the benefit being about 15 per cent. on the two smaller sizes and over 30 per cent. on the largest size. The important fact about this feature is that it results in less voltage drop at the consumers' terminals, which means improved service and increased consumption of electricity. This latter point should not be overlooked, for the loss of revenue due to voltage drop may be a very serious item.

I would like to emphasize, therefore, the value of electrical performance, and I suggest that copper loss, and particularly its effect on regulation, may be as important as iron loss. One unit of lost power by way of iron loss costs the supply authority perhaps only a fraction of a penny, but a unit lost through voltage drop due to regulation costs the authority through loss of revenue perhaps 6d., or even more. I would go

so far as to say that the operating engineer can justify the installation of transformers having the best all-round efficiency that the designer can offer.

Three-phase 4-Wire Distribution — Interconnected-star Balancers.

It is very common practice for the three-phase, 4-wire system to be used for distribution, and it is inevitable that a large part of the total load is single-phase load connected between lines and neutral, and it is impossible to maintain a permanent balance of these loads on the three phases. The current in the fourth wire is the vectorial sum of the currents in the three lines, and this would be zero for balanced loads. With unbalanced loads, however, the resultant out-of-balance current flows in the fourth wire back to the transformer, thus causing poor voltage regulation. This is particularly serious in older installations, where the fourth wire usually has a cross section much less than that of the line wires.

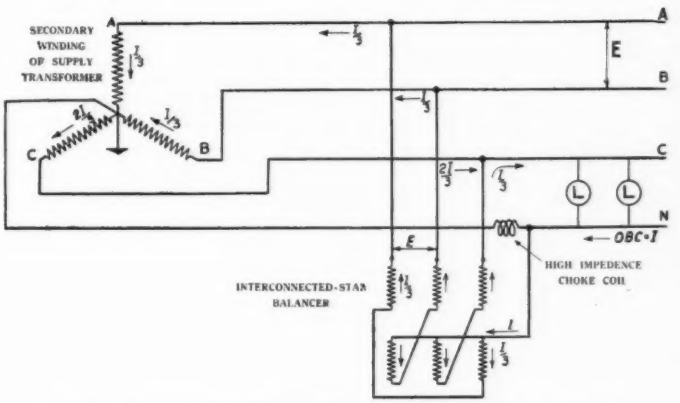
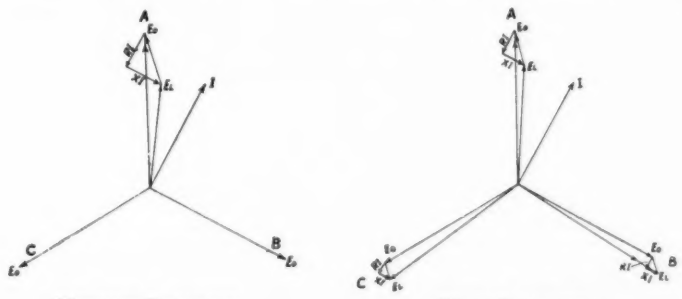


Fig. 6. Application of Interconnected-star Balancer to 3-phase 4-wire System (showing distribution of out-of-balance current).

These unsatisfactory conditions can be very much improved by the installation of interconnected-star balancers. These are connected to the system as illustrated in Fig. 6. This scheme relieves the fourth wire of the out-of-balance current and distributes the load current in better ratio between the three lines, resulting in improved voltage regulation. The effect of the use of the interconnected-star balancer is shown vectorially in Fig. 7.

For the scheme to give the best results the impedance of the fourth wire to the flow of the out-of-balance current should be high. In some cases it has been the practice to break the fourth wire, but this may not be advisable, for, even though it may be earthed at the supply point, beyond the break there would be the possibility of the line wires assuming a higher voltage than normal above earth. It is, therefore, desirable to retain the continuity of the fourth wire, and to give the effect of high impedance a choke coil is incorporated with the interconnected-star balancer, and is connected as shown in Fig. 6.

While this scheme cannot be expected to produce perfect conditions of balance and voltage regulation, great improvement is achieved. I strongly recommend the use of the interconnected star balancer, and I suggest that it should not be installed at one point only on a distributor, but that smaller units should be located at several points judiciously chosen.



Without Balancer. With Balancer.

Fig. 7. Vector Diagrams for 3-phase 4-wire System with unbalanced loading (showing effect of use of interconnected-star balancer).

(This paper will be concluded in the next issue.)

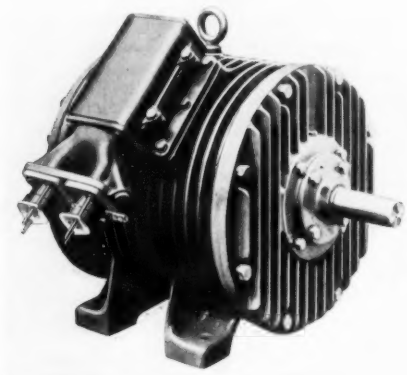
"English Electric" Motors.

Some New Developments.

(*Continued from Page 114, Vol. VI., No. 4.*)

Flameproof Motors.

To-day the use of electric power in mines is rapidly extending for all purposes from motors for winding engines and surface haulages, to those for small haulages, fans and pumps, near the coal face. In order to ensure a high degree of safety, under admittedly difficult and severe operating conditions, the Mines Department now demands a stricter compliance with the regulations governing the installation and use of electricity in mines. More complete arrangements and facilities are now in force for official inspection of apparatus installed and for carrying out representative tests of typical plant for service in mines. The "English Electric" range of flameproof alternating-current motors, both squirrel-cage and slipring up to 70 horse-power, was developed to meet the subsequent demand for a machine which would comply fully with the requirements of H.M. Inspector of Mines, and to be in accordance with the Electricity Regulations (Coal Mines Act). These motors have passed the stringent tests for flameproof enclosure at the Buxton Testing Station of the Mines Department, and the official certificates have been issued. They are of ribbed construction, and combine ample cooling surface with great strength without sacrificing the compactness which is so essential for this service. The large diameter shaft, of high-tensile steel, is supported on ball or roller bearings in dustproof self-contained housings of the cartridge type, so that the endshields or rotor may be removed from the frame without disturbing the bearings; thus avoiding the risk of exposure of the latter to dust and dirt, or faulty reassembly on the shaft. Wide, accurately machined surfaces are provided at all joints. Mica insulation is used for the coils, which are former wound and thoroughly impregnated under vacuum; this ensures the maximum uninterrupted service and reliability. Stator and rotor terminal boxes can be arranged so that the cables lead out either horizontally, upwards or downwards, which is of considerable importance where the equipment is installed in a restricted space and the cables may be fixed in some cases to the roof or alternatively on the wall. Reliable brush gear, easily adjustable is supplied on the slipring motors. The whole range of machines are the result of careful consideration of mining requirements, based on a long and varied experience of working conditions at and below the surface.

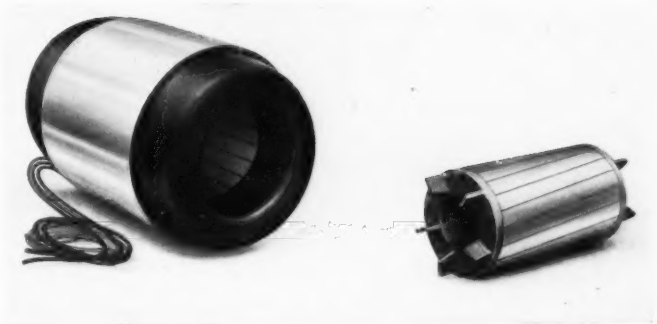


Small Flameproof Type, Squirrel-Cage Motor, Class XLK.

Squirrel-Cage "Built-in" Motors.

The use of individual electric motors for driving machinery is also continually extending both for new plant and the reorganisation of existing layouts in order to obtain the highest efficiency and best operating conditions. This is particularly noticeable in connection with high-speed machine tools and woodworking machinery, for which a shaftless driving unit has been developed for direct connection to the tool head or shaft. This—by eliminating high speed belts and their troubles—permits the designer to use constructions which were previously impossible, and results in more pleasing lines, and a more compact assembly. Since, with this "built-in" individual drive, line shafts and belts are eliminated, a

machine can be placed in the most convenient position for the performance of a particular duty in relation to the sequence of operations, without considering existing line shafts. Moreover, the minimum space is occupied, thus allowing more area for movement of operatives and handling of material or, if this is not the prime consideration for the installation of a larger number of machines. Rearrangement of plant layout to suit reorganised schemes of manufacture or to avoid unnecessary handling charges, is more easily carried out when such "built-in" motors are used. It has also been found that in many instances individual drive has made possible a reduction in the first cost of a new factory owing to the avoidance of expensive strengthening in the structure for the support of line shafts.



Typical Stator and Rotor of "Built-in" Unit.

The "English Electric" built-in alternating-current motor consists of a wound stator and a squirrel-cage rotor, and as it is designed for assembly as an integral part of the driven machine, no shaft bearings or stator frame are provided by the company; the tool manufacturer can therefore design these parts to suit his particular machine.

Bench Circular Saw, incorporating "Built-in" Motor.

The outer surface of the stator of the built-in motor is machined to close limits so that it may be pressed into the housing prepared for it in the machine tool or other unit to be driven. Former-wound, carefully insulated coils are firmly secured in the stator slots, and, after winding, are thoroughly impregnated under vacuum and specially treated to ensure the maximum protection against electrical or mechanical damage. The rotor bore is ground and keywayed to take the customer's shaft, and the complete rotor is practically indestructible. Three flexible leads, each approximately four feet in length, extend from the stator windings for connection to the starting equipment.

Output and Ratings.

A complete range of units, with high starting torque and overload capacity, is available up to 15 H.P. at 3,000 r.p.m. (synchronous speed) for 3-phase 50-cycle systems. They can be supplied for continuous or intermittent rating and for protected or total enclosure. Units can also be offered for non-standard frequencies and speeds to meet particular requirements.

Ventilation.

The rating of the units for use as protected type machines is based on the amount of cooling air circulated by the rotor fans, and as normally

supplied they are suitable for double-end ventilation. The bearing brackets and stator housing should be so constructed that the air may be drawn into the machine over the bearings at each end, and after passing over the stator windings, be discharged through openings in the housing.

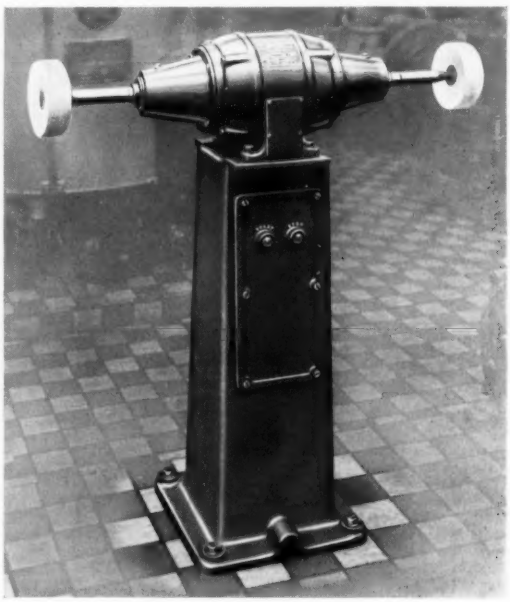
When single-end ventilation is required, where the air is drawn in through one end only and after cooling the windings is discharged at the other end, the fan at the discharged end is omitted.

A.C. Polishing Motors.

Another addition to the range of "English Electric" motors which assists in obtaining better operating conditions and reductions in running expenses is the range of alternating-current polishing or grinding motors. These motors are of the squirrel-cage type with the shaft extended at both ends of the machine. They are totally-enclosed and dustproof, and the design has been carefully considered to provide the best construction for withstanding the arduous conditions of this class of service. These robust machines are fitted with ball or roller bearings of ample size, which support a large diameter shaft of high tensile steel. In order to provide support for the shaft or spindle where this is most necessary to resist the load, and give rigidity during polishing operations, four bearings are provided; two of these being mounted in the usual manner in the endshields of the motor itself, whilst the remaining two are carried at the outer ends of projecting snouts. Although these extra bearings and snouts add considerably to the rigidity of the equipment, owing to the careful design of the machine they offer practically no more obstruction to the operator than the plain extended spindle. Grease lubrication is employed, and as the bearings are protected against dust and dirt by grease grooves and special collars, the motors will run for long periods without attention, reducing maintenance costs to a minimum. The provision of detachable noses at each end of the spindle, renders the removal or replacement of a nose, when the screw thread becomes worn, a very simple matter, as this can be carried out without dismantling the motor.

The range of polishing motors for two or three phase circuits extends up to 5 H.P. at 3,000 r.p.m. (synchronous), while for grinding service the machines are designed for 1,500 r.p.m. (synchronous). They can be supplied as bench machines or mounted on a pedestal to raise them to the correct operating height; in the latter instance a suitable starter of the contactor type may be incorporated in the pedestal so that the whole equipment is self-contained.

Polishing equipments as described can be run just when required, and stopped on completion of the work in hand, which in addition to reducing running expenses also reduces the factory noise.



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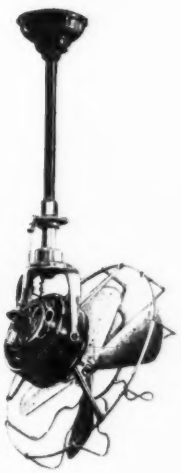

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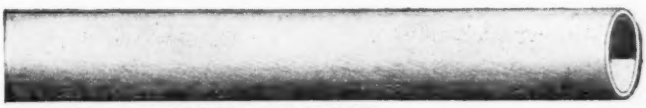

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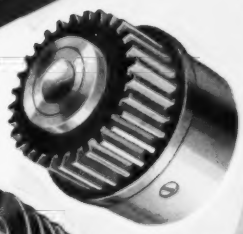

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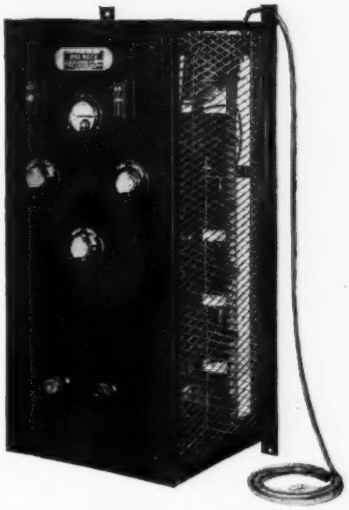

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